June 2004

June 2004 Report of Progress

James E. Alleman

Charles Glass

Jeff Volenec

Kimberly L. Jones

M. Katherine Banks

See next page for additional authors

Authors

James E. Alleman, Charles Glass, Jeff Volenec, Kimberly L. Jones, M. Katherine Banks, Albert J. Heber, Ernest R. Blatchley, Bruce Applegate, Mike Ladisch, Paul B. Brown, Cary A. Mitchell, Caula A. Beyl, Lisa J. Mauer, Leonard Williams, Joseph F. Pekny, George Chui, Yuehwern Yih, John Trimble, Julia Haines-Allen, and Dave Kotterman

June 2004 Report of Progress

1 Jim Alleman — **Solid-Phase Thermophilic Aerobic Reactor (STAR) Processing of Fecal, Food, and Plant Residues**

- **STAR Reactor Operation**

We have continued to operate our STAR reactor and have maintained routine monitoring. Daily human-fecal plus waste-food loading are currently maintained at levels comparable to 1-each crew member values and with a 6% total solids concentration. In addition, we also developed and installed new cyclic pumping strategy at 30-min interval with internal STAR recycle to negate prior episodes with solids gas entrainment and foaming. Lastly, we installed a new set of reactor thermocouples for improved, multi-point temperature monitoring.

- **STAR Off-Gas Scrubber Operation**

We developed and then started a new off-gas scrubbing system, by which residual ammonia, sulfide, mercaptans volatile fatty acid, etc. levels are now reduced to essentially non-detectable (via human nose) values.

- **STAR Reactor Monitoring**

In order to track degradation efficacy, we started new routine off-gas and reactor analysis for 'volatile fatty acids' to evaluate reactor efficacy

2 Charles Glass — **Nitrogen Cycling in ALS**

- **Optimum Zeolite for Ammonium Adsorption**

The selection of the optimum zeolite for ammonium adsorption has been completed for all of the zeolites that are currently in stock. One new zeolite, a synthetic zeolite, is on back order and we are anxiously awaiting its shipment. A chabazite is showing the highest capacity for ammonium adsorption with no pretreatment across the largest majority of the concentrations evaluated. We will continue to evaluate the capacity of new zeolites as they arrive.

- **Initial Column Assessment of STAR Condensate**

Over the past month we have received 4, 1L shipments of STAR effluent. The condensate was pumped through a column filled with 200 g of zeolite from our third best untreated zeolite (Clinoptilolite: ZS403H). The effluent from the column had no detectable NH_3-N for approximately 40 bed volumes. We will continue to examine the capability of columns filled with Chabazite: ZS500RW/H and Clinoptilolite:ZS403TM to confirm the batch study of the performance of Chabazite as the optimum zeolite for this application.

- **Pretreatment of Zeolite with Heat and KCl**

Experiments that were performed with Heat for 1, 2, or 3 hours, with soaking in KCl overnight showed no improvement in capacity for our top three zeolites. We believe that acid or base treatment may prove to be more effective and we are currently performing experiments to determine if this is true.

3 Jeff Volenec — **Solids Separation Water Removal from STAR Biosolids Effluent Using Plants**

- **STAR Biosolids Dewatering**

An experiment using human fecal waste from the Solid-Phase Thermophilic Aerobic Reactor (STAR) has been completed. The objectives of this experiment were to identify the biomass specie best suited for dewatering and capturing nutrients in STAR waste effluent and determine the mineral composition of biomass from the species used in dewatering and nutrient removal of STAR waste effluent. Experiment involved three treatments, STAR effluent, Hoagland's nutrient solution, and water, applied to eleven different plant species. All species

grown in STAR effluent exhibited reduced growth and enhanced senescence. Water transpiration increased as plant mass increased for water and Hoagland's treatments, but not with the STAR treatment. There were small differences in water use efficiency in all species tested. Plant tissue analysis is currently underway to determine differences in elemental composition of plants grown in each treatment.

- **Plant Growth Substrate**

An illite-montmorillinite-silica blend (Turface) substrate is currently being evaluated for its ability to provide increased aeration and will be included in future experiments.

4 Jim Alleman **Liquid Freeze-Thaw (LiFT) Urine & RO Brine Processing for Advanced Water Recovery and Salt Separation**

- **Freeze Concentration Technique**

After an extensive literature study and subsequent bench scale tests, a freeze concentration method of water extraction from urine seems to be the optimal method in the freeze-thaw regime. Freeze concentration is a process that sequentially uses an initial 1st-step nucleation effect to obtain pure ice seed crystals, followed by a 2nd-step ripening effect which allows these ice crystal to mature and grow, and then completed with a 3rd-step subsequent washing to achieve high extraction efficiencies. Through collaboration with a commercial leader in the freeze concentration industry, a theoretical water recovery value of approximately 90% has been determined based on the eutectic points of urine constituents. We are currently in the process of setting up experimental research via the company's pilot plant operations.

- **Bench-Scale Freeze Concentration Studies**

Currently, urine and product water are being tested for conductivity and ammonia levels. Our bench-scale testing efforts with freeze concentration have been shown that freeze concentration removes virtually all salts and ammonia, leaving a 'pure' water product with only ~1% residual contaminant levels. The current level of water recovery ranges from about 20 to 40%, due to the preliminary nature of our methodology, but continued improvements in this recovery level should be forthcoming as we continue to refine our applied treatment methodology.

- **Vacuum Drying Freeze Sublimation Technique**

No sublimation testing was completed since the last report due to our current focus on freeze-concentration.

5 Kim Jones **Membrane Processes in ALS**

- **New task: Quantify biofouling in MF system**

Students began developing methodology to quantify biofouling of MF membranes. Based on biofouling results in published literature, polyvinylidene difluoride (PVDF), polyethersulfone and PTFE membranes will be investigated for biofouling. An undergraduate student has just begun working on this project, and she will help in developing the methodology. One approach is to modify commercially available membranes by a grafting technique to reduce biofouling of the membrane. One method includes a photoinduced grafting technique using the monomers: 2-acrylamido-2-methyl-1-propanesulfonic acid (AMPS) and quaternary 2-dimethylaminoethylmethacrylate (qDMAEMA). The other method includes Interfacial polymerization between polyethyleneimine (PEI) and toluene disocyanate.

- **Ongoing tasks:**

1. Quantify flux decline and rejection in six MF membranes
2. Quantify flux decline and rejection in six RO membranes
3. Evaluate other key comparative parameters (recovery, TMP)

- **Upcoming tasks:**

1. Operate system with integrated disinfection
2. Evaluate cleaning techniques

6 Kathy Banks **Treatment of Grey Water Using Gas Biofilters**

- **Setting up Analysis protocol**

Analysis protocols for nitrogen species were established and total nitrogen, ammonia, nitrite and nitrate in BREATHe reactors were analyzed by Persulfate Digestion Method, Ion Selective Electrode Method and Ion Chromatography Instrument respectively.

- **Operation of 6 BREATHe reactors**

Six BREATHe reactors have been in operation for the month of June. Several design problems were encountered and all have been solved. The reactors have been fed with stimulant gray water. Simultaneously, clear air is also supplied to the reactors. Three of the six reactors are operating in a concurrent flow scheme and three are operating in a countercurrent flow scheme. Samples have been analyzed for total nitrogen, ammonia, nitrate and nitrite. Small levels of nitrite have recently been present (around 1 mg/L), indicating that nitrification is occurring to some level. In general, nitrite levels are increasing with time consistent with slow growth of nitrifying bacteria. Samples have been preserved so that TOC and surfactant analysis will be performed at a later date.

- **Respirometer experiments**

Further experiments have been performed using respirometry to measure biodegradation of surfactants. The surfactants in Pert Plus for Kids, SLES and DSCADA, have been examined thoroughly. Toxicity of the surfactants is not a problem, as long as bacterial are acclimated to high levels of surfactant prior tot the start of the experiment. It appears that a two step degradation process of SLES can be discerned because a lag occurs in the curve, followed by a subsequent increase in CO_2 production at a different rate. Increased replication for all experiments is currently underway to validate results. Future respirometer tests will include examination of the surfactants present in Ivory and Igepon, consistent with work going on at JSC.

7 Al Heber **Gas-Phase Revitalization Using Biofilters in ALS**

- **Biofilter Modeling**

Updated biofilter model equations.
Updated biofilter model input parameters. It is now possible to have multiple gas compounds instead of only a single kind of compound.
Updated the water flow rate in the model considering media wetting conditions.
Modeled gravity effects on gas biofiltration.
Modeled contaminant concentrations in water and gas phases with and without recycling.
Searched for input parameters from the literature.
Prepared model (Phoenics for CFD and CONTAMW 2.1 for mass transfer) and built design software using AUTOCAD.
Prepared scenarios about placement and behavior of cabin air contaminant sources.

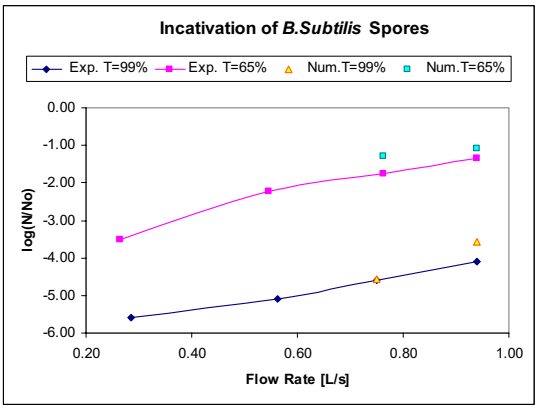
- **Biofilter Testing**

Improved the water recirculation system and nutrients addition facility.
Analyzed pre-humidification system and purchased steam generator for biofilter input gas streams.
Analyzed mechanisms of potential reactions between test gases.
Received foam media from Germany, and measured its porosity and pressure drop characteristics.

8 Chip Blatchley

Potable Water Disinfection Subject to Extended Space Travel Constraints

- **Computational Simulation of Continuous Flow Experiments**



The inactivation results of flow-through experiments performed in May were numerically simulated for two highest flow rates and two different water transmittance values. The flow field and *Bacillus subtilis* spore trajectories in the model reactor were simulated using computational fluid dynamics. The simulated spore trajectories were linked with a numerical simulation of the UV intensity field in the reactor and the UV exposure dose for each spore was calculated. Inactivation predictions for each flow rate were based on the UV dose distribution delivered by the reactor and the dose-response behavior of *Bacillus subtilis* spores determined experimentally. Inactivation predictions will be calculated for the lower flow rates to verify that the experimental and numerical results are in agreement, and that the numerical method can be used for design of a UV disinfection system that will fulfill extended space travel constraints.

- **NSCORT Summer Undergraduate Fellow**

Andy Hai-Ting of Howard University arrived at the beginning of June. Andy will be conducting experiments with *Bacillus subtilis* spores to characterize iodine and UV dose-response relationships. To date, the spores have been cultured and preliminary experiments have begun.

- **Ascorbic Acid Reactions with Iodine Solutions**

Experiments between various iodine solutions and ascorbic acid are being conducted. The objective of the experiments is to determine the amount of ascorbic acid needed to chemically reduce the iodate present in the actinometer solution. It is possible that by manipulating the actinometer composition, ascorbic acid could be used to produce I_2, which could be used as the residual disinfectant. Additional experiments will be performed to determine the feasibility.

9 Bruce Applegate
Mike Ladisch

Bioamplification Using Phage Display for the Multiplexed Detection of Pathogens in Potable Water and Food

- **Work continued using the previously constructed recombination system for the modification of the *E. coli* O157:H7 bacteriophage *phi* V10**.

Amplicons were constructed for the systematic disruption of identified open reading frames in *phi* V10. We are currently beginning the recombination and lysogen rescue experiments. (Note: An anomaly in the previously reported sequencing data suggests a unique DNA packaging requirement for *phi* V10 which is being investigated. It appears the phage may have a tripartite genome. If this is the case it would allow large insertions of foreign DNA.)

- **Work was continued on the insertion of a unigue binding epitope in the tailspike protein of the *Salmonella* spp. bacteriophage P22.**

Appropriate promoter and terminator configurations were added to the modified tailspike protein to allow repressed expression of the His modified tailspike protein in the preparative host strain. Preparative host strain containing the *lacI* repressor gene cassette was constructed. The strain is currently being evaluated for sufficient repression activity using a *lac-lux* fusion.

- **Initial work on a Listeria phage based assay was begun.**

Preciaus Heard (Summer Fellowship Student) began initial screening of a *Listeria monocytogenes* library to isolate a lysogenic bacteriophage. Preliminary results suggest she was successful and we are currently further evaluating the isolated bacteriophage and continuing to screen the library.

10 Paul Brown **Waste Treatment Using Tilapia**

- **Waste minimization evaluation enters 4th week**

Working with collaborators in Civil Engineering, Horticulture and Agronomy, we collected 6 waste products for evaluation. All products were dried and pelleted and are being fed to juvenile tilapia. All waste products are being consumed by fish, but at differential rates.

- **Integration of aquaculture and hydroponics evaluation set to begin**

In a preliminary evaluation of the linkage between fish culture and hydroponics production of plants, we identified gross signs of mineral deficiency in several species of plants. We established an experimental system to further explore this problem, diets have been formulated and the project should begin in the next month.

- **Value of fish as a food source**

Whole fish, fillets and remaining carcasses after filleting were collected, dried and are being analyzed as a food source for the crews. Complete macro- and micronutrient analyses are underway.

11 Cary Mitchell **Minimizing ESM for ALS Crop Production**

- **LED lighting system construction for Purdue by Orbitec continued.**

Mounting assembly work at Purdue also was ongoing**.**

- **Sweetpotato third replicate of container volume/shoot pruning experiment harvested.**

Roots were sent off for proximate composition analysis by Dr. Mauer's lab.

- **Photosynthesis measurements of individual leaves were taken for sweetpotato single-vine treatments, and roots were then harvested.**

High rates of photosynthesis were measured along 20-foot-long vines, with the lowest rates occurring at the base and apical tip.

- **•Harvest of eight basil cultivars maintained at different heights.**

Yield of edible fresh biomass was compared for each cultivar.

- **•Bruce Applegate collected hydroponics solution samples.**

He is looking at possible anti-bacterial effects of leachates from cowpea roots, which maintain optically clear solutions throughout crop production.

12 Caula Beyl **Solid Waste Processing Using Edible Fungi**

- **Enhancing growth and fruiting of edible fungi on wheat straw using urea**

Three edible fungal species were grown in fine wheat straw (≤ 2 mm particle size) amended with urea at 0.0, 0.001, 0.01, 0.05 and 0.1M as N source. This project was carried out by our Undergrad Summer Fellowship trainee in order to determine optimal concentrations of N for growth and fruiting, and to compare the relative growth and fruiting of three fungal species *Pleurotus ostreatus*, *Grifola frondosa* and *Lentinula edodes*, on the enriched fine wheat straw. Preliminary observations show that *P. ostreatus* (strain Grey dover) is most responsive whilst urea at 0.001M is most favorable to mycelial colonization. Other parameters being evaluated include change in pH and C/N ratio over time, time to first fruiting and basidiocarp production.

- **Cropping mixed spent crop substrate with strains of shiitake, oyster and maitake**

To minimize residual undegraded crop substrate following initial cropping, it is imperative to identify species and strains of edible fungi that can further colonize the non-degraded portion of previously cropped biomass. This will ensure continued degradation and recycling of the residual crop biomass in ALS system. Spent wheat straw, rice straw, sweetpotato, basil, tomato, cowpea and soybean including those contaminated by competing fungal species were thoroughly mixed, autoclaved and seeded separately with *Pleurotus spp*, *L. edodes* and *G. frondosa.* Initial mycelial colonization shows that *Pleurotus* species colonize most rapidly compared to *Lentinula* and *Grifola*. Growth of *G. frondosa* in these media so far has been repressed.

- **Soaking milled residual crop biomass as an alternative to autoclaving**

Commercial mushroom spawn producers have indicated that soaking wheat straw in water reduces or eliminates competing contaminating microorganisms in the spawn. If successful, this practice will curtail the tremendous energy inputs and mass associated with autoclaving for sterilization of crop substrates. Processed rice straw was soaked in tap water for 48 h. The amount of water retained was reduced by manually squeezing the straw to approximately 40% moisture content. About 80 g of the soaked material was placed in 750ml food containers and inoculated with three edible fungal species (*P. ostreatus*, *L. edodes* and *G. frondosa*) separately. Cultures were incubated at 24°C for growth and fruiting.

13 Lisa Mauer **Novel Storage and Packaging Operations**

- **Work is continuing on an experimental design for determining effects of irradiation on oil and antioxidant quality parameters**

Oil and antioxidant samples have been obtained and preliminary studies into the best analytical methods for evaluating oil (TBARS, GC-MS, FTIR) and antioxidant stability (TRAP, FRAP, ORAC, Randox test kit) are underway. For antioxidant measurements, the FRAP method was selected as the best for all sample types being considered. We are continuing our search for a "good" source of radiation for the samples we will be using. We have had some difficulty with this, and with price estimates for large enough sample volumes to allow for a storage study, but we are hoping to get this resolved in the next 2 months.

- **We are continuing to develop a foods lab to be used in the Purdue NASA camp August 4-6 and to develop a presentation on foods to be included in a space exploration course for the Wabash Area Lifetime Learning Association that will begin in October.**

The hands-on foods lab will consist of a series of experiments: 1) using a vacuum to see how different foods react to vacuum conditions; 2) using a variety of freeze-dried foods to investigate hydration and food acceptability; and 3) making tortillas from wheat berries going through all preparation steps from grinding, dough formation, baking/dehydration, and ending with frying.

- **Sweetpotato collaborative study (Cary Mitchell)**

We have received sweetpotato samples from the third growth replicate and are organizing proximate and vitamin A analyses for these.

- **PI Mauer back part-time from maternity leave**
- **Beginning experimental design for a collaborative organoleptic study on effects of basil in the diet of tilapia on acceptability of fish fillets consumed after baking (Paul Brown)**

Sensory data to be collected this fall. New regulations at Purdue will require Lisa Mauer to undergo a workshop prior to receiving approval for human subjects testing needed for this project.

14 Leonard Williams — Optimal Food Safety in ALS

- **Completing preliminary work on the use of pulsed light sterilization and in combination with disinfectants on reduction of spoilage bacteria on lettuce (in collaboration with Microcide,Inc., Dr. Lopes)**
- **Use of impedance technology to determine the growth of biofilms on salad crop (lettuce).**
- **Determination of potential critical control points in pre-harvest salad crop production.**

15 J. Pekny, G. Chiu, Y. Yih — Systems Modeling of ALS

- **Completion of functioning NSCORT mass balance model**

This month has seen the completion of a model of all mass flows in a life support system relying uniquely on proposed NSCORT technologies. As expected, the model has an Excel interface to unify all specifications of process connectivity, stream compositions, mass and concentration values, reaction stoichiometry, phase equilibria, and other relations. The underlying code solves a linear program currently having 947 variables and 711 equations. The model finds feasible solutions including operation of all air, water, and waste recovery processes, growth of 15 crops, edible fungi, tilapia, and six biosolids dewatering plants. The air and water loops are evidently closed, and food is mainly supplied based on the current choice of costs for supply vs. growth. Biomass production is minimized in general.

- **Training of personnel for responsibilities**

Dr. George Applequist has provided training, documentation, and all modeling files for the three systems graduate students, as well as the progress report and project plan at the June 25 NSCORT meeting.

- **Future work**

Through trials and validation of the mass balance model this summer, the group will find requirements for more data and constraints, then refine the model and increase the realism of the solutions. The design of the system, illustrated by the process map, will also evolve. Later this year, energy and ESM may be

taken into account.

16 John Trimble **A System Dynamics Approach to Modeling the Advance Life Support System**

- No report submitted

17 Julia Hains-Allen **Outreach**

- **Summer Fellowship Program**

Seven undergraduate students began the Summer Fellowship Program on June 6, 2004. Four students from Howard University and three students from Alabama University were chosen by the fellowship committee.

- **Key Learning Explore Mars Camp**

$2,000 in additional funding was obtained from the NASA Nano Technology Hub at Purdue University. That funding raises the total amount granted to Julia Hains-Allen from proposals for the funding of this camp to $20,000.

- **Project Lead The Way**

Three Biomass Production Educational Systems (BPES) were delivered from Orbitec to Education/Outreach in June. Research and curriculum development are underway. Julia Hains-Allen, Macon Fish (ALS/NSCORT graduate student) and a Project Lead The Way teacher Jeff Martin are developing the 18 week learning module. Graduate student Yong Sang Kim is assisting in development of the ESM module development. A pilot study begins September 1, 2004 in 10 Indiana high schools. The pilot study will be consist of Biology, Chemistry or Agriculture teachers teaming with Math and English teachers in their respective buildings. The teams will be growing plants in the BPES, calculating Equivalent System Mass (ESM), and writing research papers.

- **Agriculture Teachers Conference**

Julia Hains-Allen presented the Mission To Mars module and the Project Lead The Way material to 50 agriculture educators at a conference held at Purdue University. As a result of this presentation, five agriculture teachers have completed applications to participate in the Project Lead The Way pilot and four agriculture teachers are incorporating Mission To Mars into their curriculum. More participation is expected in the coming months.

18 Dave Kotterman **ALS NSCORT Center Activities**

- **Center supported Strategic Research to Enable NASA's Exploration Missions in Cleveland Ohio.**

Jim Alleman represented the ALS NSCORT on June 22 & 23 in support of this important conference.

- **NASA/JSC Water Meeting in Houston, Texas.**

Kathy Banks represented the ALS NSCORT on June 24 & 25 in support of the advancement of water research.

- **ALS NSCORT Center-wide Research Progress Meeting.**

This meeting on June 25th gave forum to representatives from all sixteen research projects to present project plan milestones met, communicate successes as well as tall tent-poles experienced, and project plans for the next 90 days. This quarterly meeting will continue throughout 2004.